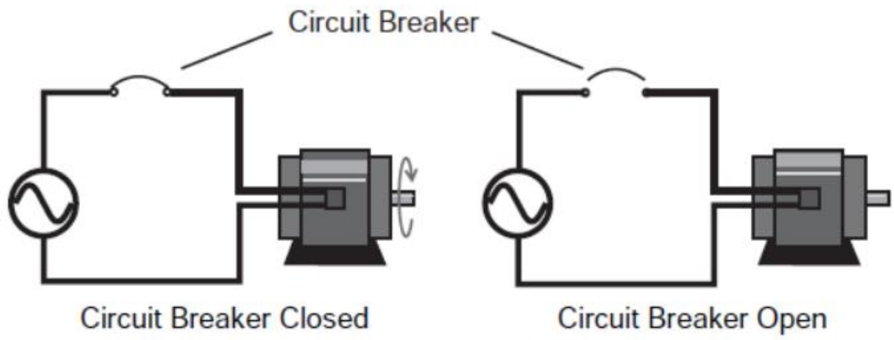
COURSE TITLE: ELECTRICAL SYSTEM COMPONENTS

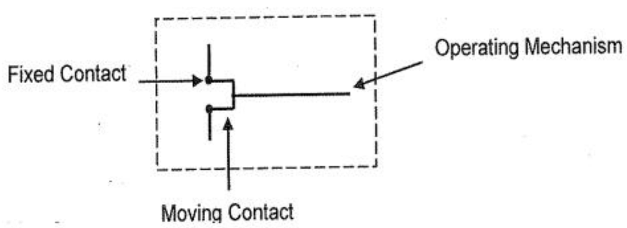
Lesson III: CIRCUIT BREAKERS

Circuit breakers provide a manual means of energizing and de-energizing a circuit. Unlike fuses, which must be replaced when they open, a circuit breaker can be reset once the overcurrent condition has been corrected. Pushing the handle to the "OFF" position then back to the "ON" position restores the circuit. If a circuit reopens upon reset to the "ON" position, the circuit should be checked by a qualified electrician.

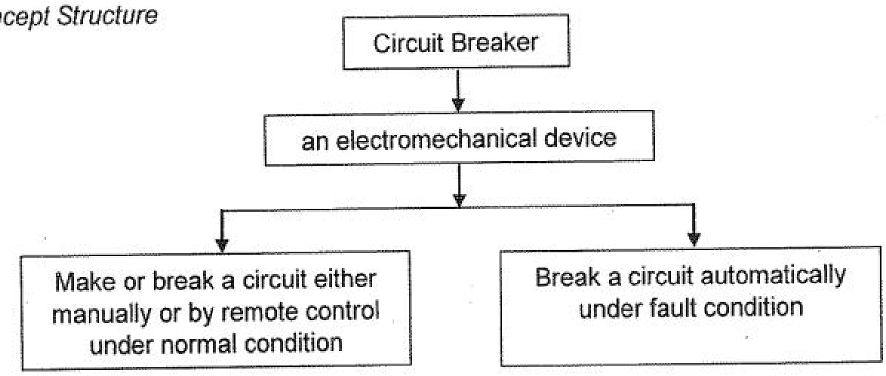
I.1- Fundamental of Circuit Breaker operation

In the following illustration, an AC motor is connected through a circuit breaker to a voltage source. When the circuit breaker is closed, a complete path for current exists between the voltage source and the motor allowing the motor to run. Opening the circuit breaker breaks the path of current flow and the motor stops. The circuit breaker automatically opens when it senses a fault. After the fault has been cleared, the breaker can be closed, allowing the motor to operate.





Concept Structure



I.2- Formation of an arc duringcircuit breaking

I.2.1 The phenomena of Arc

During opening of current carrying contacts in a circuit breaker the medium in between opening contacts become highly ionized through which the interrupting current gets low resistive path and continues to flow through this path even after the contacts are physically separated. During the flowing of current from one contact to other the path becomes so heated that it glows in the form of an arc.

I.2.2 Arc in circuit breaker

Whenever, the contacts of circuit breaker open while carrying load there is an arc in the medium between the separating contacts of the circuit breaker. As long as this arc is sustained in between the contacts, the current through the circuit breaker will not be interrupted totally. For total interruption of current, the arc needs to be quenched as quickly as possible. The main designing criteria of a circuit breaker is to provide appropriate technology of arc quenching in circuit breaker to fulfill quick and safe current interruption. So before going through different arc quenching techniques employed in circuit breaker, it is first necessary to understand the phenomena of arc in circuit breaker.

THERMAL IONIZATION OF GAS

There are numbers of free electrons and ions present in the medium separating the two contacts of the circuit breaker. These free electrons and ions are so few in number that they are insufficient to sustain conduction of electricity. The gas molecules move randomly at room temperature. It is found an air molecule at a temperature of 300°K (Room temperature) moves randomly with an approximate average velocity of 500 meters/second and collides other molecules at a rate of 10 times/second. These randomly moving molecules collide each other in very frequent manner but the

kinetic energy of the molecules is not sufficient to extract an electron from atoms of the molecules. If the temperature is increased the air will be heated up and consequently the velocity on the molecules increased. Higher velocity means higher impact during inter molecular collision. During this situation some of the molecules are disassociated in to atoms. If temperature of the air is further increased many atoms are deprived of valence electrons and make the gas ionized. Then this ionized gas can conduct electricity because of sufficient free electrons. This condition of any gas or air is called plasma. This phenomenon is called thermal **ionization of gas**.

IONIZATION DUE TO ELECTRIC FILED

As we discussed that there are always some free electrons and ions presents in the air or gas but they are insufficient to conduct electricity. Whenever these free electrons come across a strong electric field, these are attracted by the field and acquire sufficiently high velocity. In other words, the electrons are accelerated along the direction of the electric field due to high potential gradient. During their travel these electrons collide with other atoms and molecules of the air or gas and extract valance electrons from their orbits. After extracted from parent atoms, the electrons will also run along the direction of the same electric field due to potential gradient. These electrons will similarly collide with other atoms and create more free electrons which will also be directed along the electric field. Due to this conjugative action the numbers of free electrons in the gas will become so high that the gas starts conducting electricity. This phenomenon is known as ionization of gas due to electron collision.

DEIONIZATION OF GAS

If all the causes of ionization of gas are removed from an ionized gas it rapidly come back to its neutral state by recombination of the positive and negative charges. The process of recombination of positive and negative charges is known as deionization process. In deionization by diffusion, the negative ions or electrons and positive ions move to the walls under the influence of concentration gradients and thus completing the process of recombination.

I.2.3 Role of arc in circuit breaker

When two current carrying contacts open, an arc bridges the contact gap through which the current gets a low resistive path to flow so there will not be any sudden interruption of current. As there is no sudden and abrupt change in current during opening of the contacts, there will not be any abnormal switching over voltage in the

system. Let i is the current flowing through the contacts just before they open and L is the system inductance, switching over voltage during opening of contacts, may be expressed as V = L.(di/dt) where di/dt rate of change of current with respect to time during opening of the contacts. In the case of alternating current arc is momentarily extinguished at every current zero. After crossing every current zero the medium between separated contacts gets ionized again during next cycle of current and the arc in circuit breaker is reestablished. To make the interruption complete and successful, this re-ionization in between separated contacts to be prevented after a current zero.

If arc in circuit breaker is absence during opening of current carrying contacts, there would be sudden and abrupt interruption of current which will cause a huge switching overvoltage sufficient to severely stress the insulation of the system. On the other hand, the arc provides a gradual but quick, transition from the current carrying to the current breaking states of the contacts.

I.3- Arc Interruption or Arc Quenching

There are two methods by which interruption is done.

1. High resistance method.
2. Low resistance method or zero interruption method.

In high interruption method we can increase the electrical resistance many times to such a high value that it forces the current to reach to zero and thus restricting the possibility of arc to be struck again. Proper steps must be taken in order to ensure that the rate at which the resistance is increased or decreased is not abnormal because it may lead to generation of harmful induced voltages in the system. The arc resistance can be increased by various methods like lengthening or cooling of the arc etc.

Limitations of high resistance method: Arc discharge has a resistive nature due to this most of the energy is received by circuit breaker itself hence proper care should be taken during the manufacturing of circuit breaker like mechanical strength etc. Therefore this method is applied in dc power circuit breaker, low and medium ac power circuit breaker.

Low resistance method is applicable only for ac circuit and it is possible there because of presence of natural zero of current. The arc gets extinguished at the

natural zero of the ac wave and is prevented from restricting again by rapid building of dielectric strength of the contact space.

There are two theories which explains the phenomenon of arc extinction:

1. Energy balance theory,
2. Voltage race theory.

Before going in details about these theories, we should know the following terms.

Restriking voltage: It may be defined as the voltage that appears across the breaking contact at the instant of arc extinction.

Recovery voltage : It may be defined as the voltage that appears across the breaker contact after the complete removal of transient oscillations and final extinction of arc has resulted in all the poles.

Active recovery voltage : It may be defined as the instantaneous recovery voltage at the instant of arc extinction.

Arc voltage : It may be defined as the voltage that appears across the contact during the arcing period, when the current flow is maintained in the form of an arc. It assumes low value except for the point at which the voltage rise rapidly to a peak value and current reaches to zero.

a-Energy Balance Theory

When the contact of circuit breaker are about to open, re striking voltage is zero, hence generated heat would be zero and when the contacts are fully open there is infinite resistance, therefore no production of heat again. We can conclude from this that the maximum generated heat is lying between these two cases and can be approximated, now this theory is based on the fact that, if the rate of generation of heat between the contacts of circuit breaker is lower than the rate at which heat between the contact is dissipated, then the established arc shall be extinguished successfully. Thus if it is possible to remove the generated heat by cooling, lengthening and splitting the arc at a high rate the generation, arc can be extinguished.

b-Voltage Race Theory

The arc is due to the ionization of the gap between the contact of the circuit breaker. Thus the resistance at the initial stage is very small i.e. when the contact are closed and as the contact separates the resistance starts increasing. If we remove ions at the initial stage either by recombining them into neutral molecules or inserting insulation at a rate faster than the rate of ionization, the arc can be interrupted. The ionization at zero current depends on the restriking voltage. The theory states that

if the rate of rise of restriking voltage is lesser than the rate at which the dielectric strength of the medium increases, then the arc will be successfully extinguished.

I.4- Rating of Circuit Breaker

The rating of a circuit breaker includes,

1) Rated short circuit breaking current.

2) Rated short circuit making current.

3) Rated operating sequence of circuit breaker.

4) Rated short time current.

I.4.1 Short circuit breaking current of circuit breaker

This is the maximum short circuit current which a circuit breaker can withstand before it. Finally cleared by opening its contacts. When a short circuit flows through a circuit breaker, there would be thermal and mechanical stresses in the current carrying parts of the breaker. If the contact area and cross-section of the conducting parts of the circuit breaker are not sufficiently large, there may be a chance of permanent damage in insulation as well as conducting parts of the CB.

The short circuit current has a certain value at the instant of contact separation. The breaking current refers to value of current at the instant of the contact separation. The rated values of transient recovery voltage are specified for various rated voltage of circuit breakers. For specified conditions of rated TRV and rated power frequency recovery voltage, a circuit breaker has a certain limit of breaking current. This limit is determined by conducting short circuit type tests on the circuit breaker. The waveforms of short circuit current are obtained during the breaking test. The evaluation of the breaking current is explained in Fig. 3. The breaking current is expressed by two values. The r.m.s values of a.c. components are expressed in KA. the standard values being 8, 10, 12.5, 16, 20, 25, 31.5, 40, 45, 63, 80 and 100KA.

The earlier practice was to express the rated breaking capacity of a circuit breaker in terms of MVA given as follows

Rated Breaking MVA capacity = $\sqrt{3}$ x KV x KA

Where MVA = Breaking capacity of a circuit breaker kV KV = Rated voltage

KA = Rated breaking current

This practice of specifying the breaking capacity in terms of MVA is convenient while calculating the fault levels. However, as per the revised standards, the breaking capacity is expressed in KA for specified conditions of TRV and this method takes

into account both breaking current and TRV. The breaking capacity can be both symmetrical and asymmetrical in nature. In asymmetrical breaking capacity the DC component of the current is added.

While selecting the circuit breaker for a particular location in the power system the fault level at that location is determined. The rated breaking current can then be selected from standard range.

I.4.2 Rated short circuit making capacity

The short circuit making capacity of circuit breaker is expressed in peak value not in rms value like breaking capacity.It may so happen that circuit breaker may close on an existing fault. In such cases the current increase to the maximum value at the peak of first current loop. The circuit breaker should be able to close without hesitation as contact touch. The circuit breaker should be able to withstand the high mechanical forces during such a closure. These capabilities are proved by carrying out making current test. The rated short circuit making current of a circuit breaker is the peak value of first current loop of short circuit current (I pk)Which the circuit breaker is capable of making at its rated voltage.

The rated short circuit making current should be least 2.5 times the r.m.s. value of a.c. component of rated breaking current .

Rated making current = 1.8 x √2 x Rated short circuit breaking

= 2.5 x Rated short circuit breaking current

In the above equation the factor √2 convert the r.m.s value to peak value. Factor 1.8 takes into account the doubling effect of short circuit current with consideration to slight drop in current during the first quarter cycle.

I.4.3 Rated operating sequence or duty cycle of circuit breaker

This is mechanical duty requirement of circuit breaker operating mechanism. The sequence of rated operating duty of a circuit breaker has been specified as

O – t – CO – t'' – CO

Where O indicates opening operation of the CB. CO represents closing operation immediately followed by an opening operation without any intentional time delay. t'' is time between two operations which is necessary to restore the initial conditions and / or to prevent undue heating of conducting parts of circuit breaker. t = 0.3 sec for circuit breaker intended for first auto re closing duty, if not otherwise specified.

Suppose rated duty circle of a circuit breaker is 0 – 0.3 sec – CO – 3 min – CO.

This means, an opening operation of circuit breaker is followed by a closing operation after a time interval of 0.3 sec, then the circuit breaker again opens without any intentional time delay. After this opening operation the CB is again closed after 3 minutes and then instantly trips without any intentional time delay.

I.4.4 Rated short time current

This is the current limit which a circuit breaker can carry safely for certain specific time without any damage.

The circuit breakers do not clear the short circuit current as soon as any fault occurs in the system. There always some intentional and an intentional time delays present between the instant of occurrence of fault and instant of clearing the fault by CB. This delay is present because of time of operation of protection relays, time of operation of circuit breaker and also there may be some intentional time delay imposed in relay for proper coordination of power system protection. Hence, after fault, a circuit breaker has to carry the short circuit for certain time. The summation of all time delays should not be more than 3 seconds, hence a circuit breaker should be capable of carrying a maximum fault current for at least this short period of time.

The short circuit current may have two major affects inside a circuit breaker.

1. Because of the high electric current, there may be high thermal stress in the insulation and conducting parts of CB.
2. The high short circuit current, produces significant mechanical stresses in differentcurrent carrying parts of the circuit breaker.

A circuit breaker is designed to withstand these stresses. But no circuit breaker has to carry a short circuit current not more than a short period depending upon the coordination of protection. So it is sufficient to make CB capable of withstanding affects of short circuit current for a specified short period.

The rated short time current of a circuit breaker is at least equal to rated short circuit breaking current of the circuit breaker.

I.4.5 Rated voltage of circuit breaker

Rated voltage of circuit breaker depends upon its insulation system. For below 400 KV system, the circuit breaker is designed to withstand 10% above the normal system voltage. For above or equal 400 KV system the insulation of circuit breaker should be capable of withstanding 5% above the normal system voltage. That means, rated voltage of circuit breaker corresponds to the highest system voltage. This is

because during no load or small load condition the voltage level of power system is allowed rise up to highest voltage rating of the system.

A circuit breaker is also subject to two other high voltage condition.

1) Sudden disconnection of huge load for any other cause, the voltage imposed on the CB and also between the contacts when the CB is open, may be very high compared to higher system voltage. This voltage may be of power frequency but does not stay for very long period as this high voltage situation must be cleared by protective switchgear.

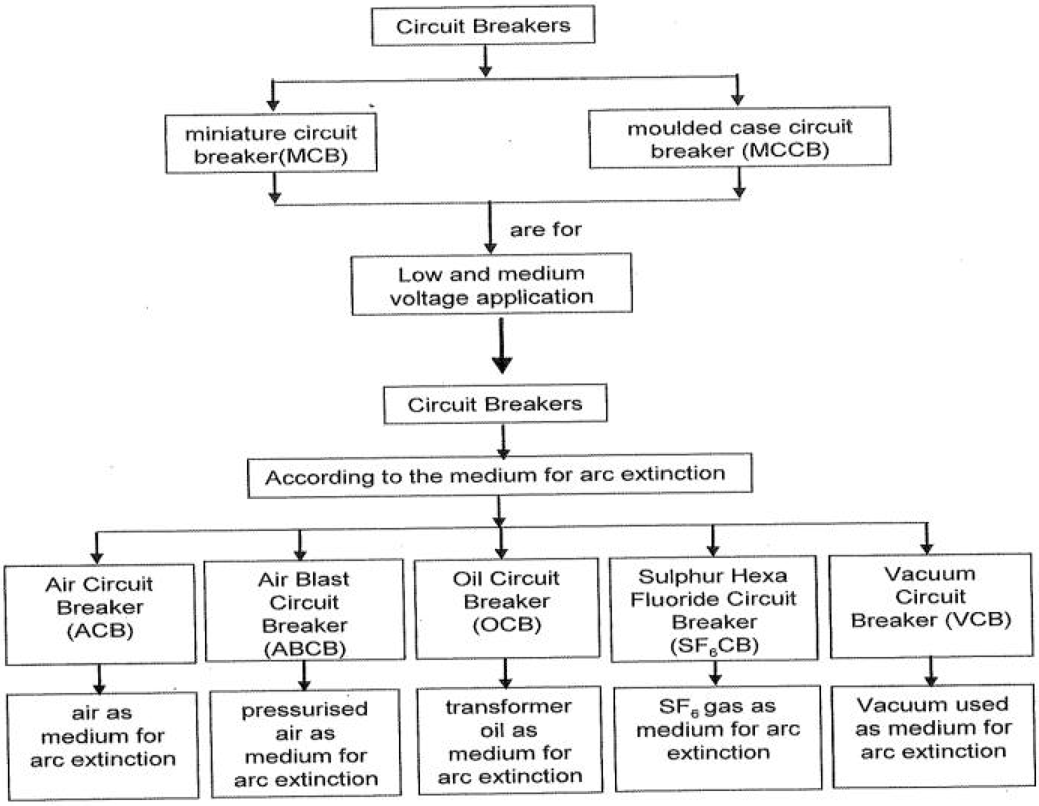
But a circuit breaker may have to withstand this power frequency over voltage, during its normal life span.

The Circuit Breaker must be rated for power frequencies withstand voltage for a specific time only. Generally the time is 60 seconds. Making power frequency withstand capacity, more than 60 second is not economical and not practically desired as all the abnormal situations of electrical power system are definitely cleared within much smaller period than 60 seconds.

2) Like other apparatuses connected to power system, a circuit breaker may have also to face lightening impulse and switching impulses during its life span.

The insulation system of CB has to withstand these impulse voltage waveform. So a circuit breaker is designed to withstand this impulse peaky voltage for microsecond range only.

NOMINAL SYSTEM VOLTAGE	HIGHEST SYSTEM VOLTAGE	POWER FREQUENCY WITHSTAND VOLTAGE	IMPULSE VOLTAGE LEVEL
11 KV	12 KV	–	–
33 KV	36 KV	70 KV	170 KV
132 KV	145 KV	275 KV	650 KV
220 KV	245 KV	460 KV	1050 KV
400 KV	420 KV	–	–



I.5- Air Circuit Breaker and Air Blast Circuit Breaker

This type of circuit breakers, is those kind of circuit breaker which operates in air at atmospheric pressure. After development of oil circuit breaker, the medium voltage air circuit breaker (ACB) is replaced completely by oil circuit breaker in different countries. But in countries like France and Italy, ACBs are still preferable choice up to voltage 15 KV. It is also good choice to avoid the risk of oil fire, in case of oil circuit breaker. In America ACBs were exclusively used for the system up to 15 KV until the development of new vacuum and SF6 circuit breakers.

I.5.1 Working principle of air circuit breaker(ACB)

The working principle of this breaker is rather different from those in any other types of circuit breakers. The main aim of all kind of circuit breaker is to prevent the reestablishment of arcing after current zero by creating a situation where in the contact gap will withstand the system recovery voltage. The air circuit breaker does the same but in different manner. For interrupting arc it creates an arc voltage in excess of the supply voltage. Arc voltage is defined as the minimum voltage required maintaining the arc. This circuit breaker increases the arc voltage by mainly three different ways,

1. It may increase the arc voltage by cooling the arc plasma. As the temperature of arc plasma is decreased, the mobility of the particle in arc plasma is reduced, hence more voltage gradient is required to maintain the arc.
2. It may increase the arc voltage by lengthening the arc path. As the length of arc path is increased, the resistance of the path is increased, and hence to maintain the same arc current more voltage is required to be applied across the arc path. That means arc voltage is increased.
3. Splitting up the arc into a number of series arcs also increases the arc voltage.

The first objective is usually achieved by forcing the arc into contact with as large an area as possible of insulating material. Every air circuit breaker is fitted with a chamber surrounding the contact. This chamber is called „arc chute". The arc is driven into it. If inside of the arc chute is suitably shaped, and if the arc can conform to the shape, the arc chute wall will help to achieve cooling. This type of arc chute should be made from some kind of refractory material. High temperature plastics reinforced with glass fiber and ceramics are preferable materials for making arc chute.

The second objective that is lengthening the arc path is achieved concurrently with the first objective. If the inner walls of the arc chute is shaped in such a way that the arc is not only forced into close proximity with it but also driven into a serpentine channel projected on the arc chute wall. The lengthening of the arc path increases the arc resistance.

The third objective is achieved by using metal arc slitter inside the arc chute. The main arc chute is divided into numbers of small compartments by using metallic separation plates. These metallic separation plates are actually the arc splitters and each of the small compartments behaves as individual mini arc chute. In this system the initial arc is split into a number of series arcs, each of which will have its own mini arc chute. So, each of the arc splits has its own cooling and lengthening effect. This collectively, increases the overall arc voltage and helps in quenching.

3.5.2 Types of ACB

There are mainly two types of ACB are available.

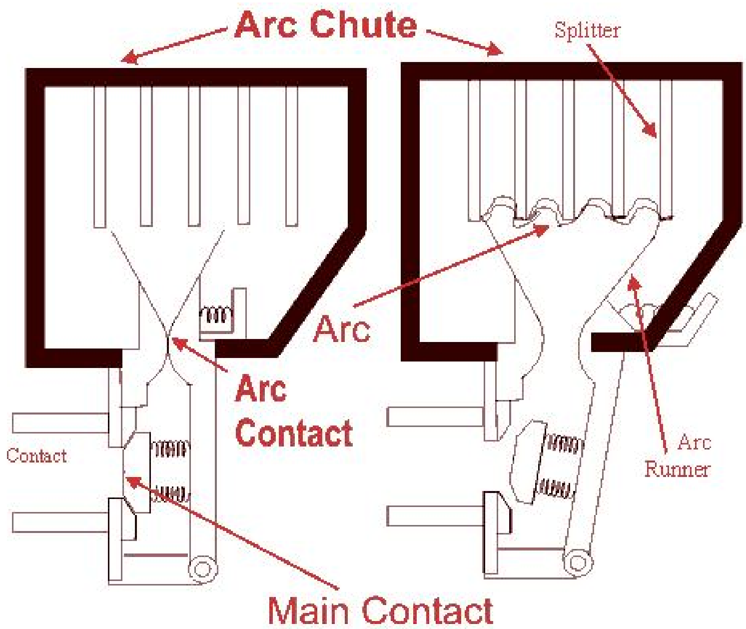
1. Plain air circuit breaker.

The above method explains the working principle of plain break type air circuit breakers.

2. Controlled Break Circuit breakers.

Operation of Controlled break ACB

The air circuit breaker, operated within the voltage level 1 KV, does not require any arc control device. Mainly for heavy fault current on low voltages (low voltage level above 1 KV) ABCs with appropriate arc control device, are good choice. These breakers normally have two pairs of contacts. The main pair of contacts carries the current at normal load and these contacts are made of copper. The additional pair is the arcing contact and is made of carbon. When circuit breaker is being opened, the main contacts open first and during opening of main contacts the arcing contacts are still in touch with each other. As the current gets, a parallel low resistive path through the arcing contact during opening of main contacts, there will not be any arcing in the main contact. The arcing is only initiated when finally the arcing contacts are separated. The arc contact is fitted with an arc runner which helps the arc discharge to move upward due to both thermal and electromagnetic effects as shown in the figure below. As the arc is driven upward it enters in the arc chute, consisting of splitters. The arc in chute will become colder, lengthen and split hence arc voltage becomes much larger than system voltage and therefore the arc is quenched finally durent the current zero.



Although this type of circuit breakers have become obsolete for medium voltage application, but they are still preferable choice for high current rating in low voltage application.

I.5.3 AIR BLAST CIRCUIT BREAKER

These types of air circuit breaker were used for the system voltage of 245 KV, 420 KV and even more, especially where faster breaker operation was required. Air

blast circuit breaker has some specific advantages over oil circuit breaker which are listed as follows,

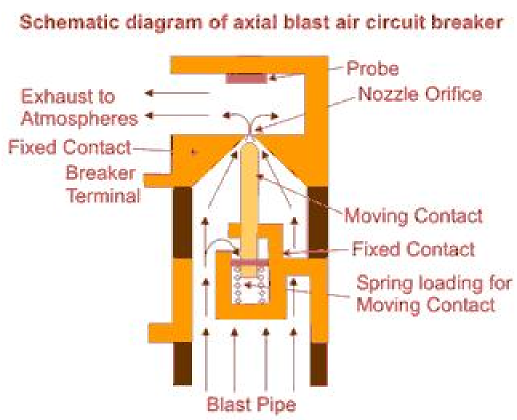
1. There is no chance of fire hazard caused by oil.
2. The breaking speed of circuit breaker is much higher during its operation.
3. Arc quenching is much faster.
4. The duration of arc is same for all values of small as well as high currents interruptions.
5. As the duration of arc is smaller, so lesser amount of heat is generated, which ensures longer service life of the contacts.
6. The stability of the system can be well maintained as it depends on the speed of operation.
7. Requires much less maintenance compared to oil circuit breaker.

Some of the disadvantages of using ABCB are as follows

1. In order to have frequent operations, it is necessary to have sufficiently high capacity air compressor.
2. Frequent maintenance of compressor, associated air pipes and automatic control equipments is also required.
3. Due to high speed current interruption there is always a chance of high rate of rise of re- striking voltage and current chopping.
4. There also a chance of air pressure leakage from air pipes junctions.

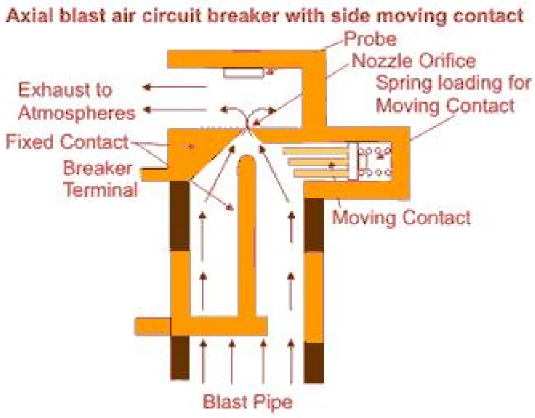
As we said earlier that there are mainly two types of ACB, plain air circuit breaker and air blast circuit breaker. But the later can be sub divided further into three different categories.

a-Axial Blast ACB.



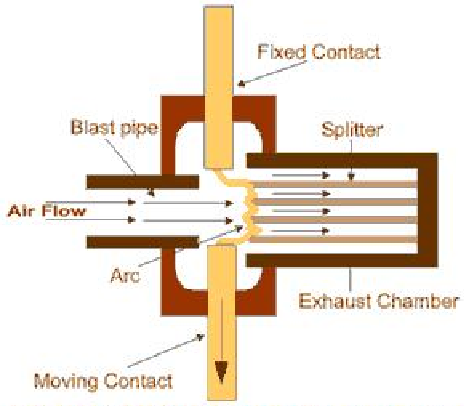
In axial blast ACB the moving contact is in contact with fixed contact with the help of a spring pressure as shown in the figure above. There is a nozzle orifice in the fixed contact which is blocked by tip of the moving contact at normal closed condition of the breaker. When fault occurs, the high pressure air is introduced into the arcing chamber. The air pressure will counter the spring pressure and deforms the spring hence the moving contact is withdrawn from the fixed contact and nozzle hole becomes open. At the same time the high pressure air starts flowing along the arc through the fixed contact nozzle orifice. This axial flow of air along the arc through the nozzle orifice will make the arc lengthen and colder hence arc voltage become much higher than system voltage that means system voltage is insufficient to sustain the arc consequently the arc is quenched.

b-Axial Blast ACB with side moving contact.



In this type of axial blast air circuit breaker, the moving contact is fitted over a piston supported over a spring. In order to open the circuit breaker the air is admitted into the arcing chamber when pressure reaches to a predetermined value, it presses down the moving contact. An arc is drawn between the fixed and moving contacts. The air blast immediately transfers the arc to the arcing electrode and is consequently quenched by the axial flow of air.

c-Cross Blast ACB.



Principle of Cross Blast Air Circuit Breaker

The working principle of cross blast air circuit breaker is quite simple. In this system, a pipe is fixed in perpendicular to the movement of moving contact in the arcing chamber and on the opposite side of the arcing chamber one exhaust chamber is also fitted at the same alignment of blast pipe, so that the air comes from blast pipe can straightly enter into exhaust chamber through the contact gap of the breaker. The exhaust chamber is split with arc splitters. When moving contact is withdrawn from fixed contact, an arc is established in between the contact, and at the same time high pressure air coming from blast pipe will pass through the contact gapradially, and the high pressure air blast will forcefully take the arc into exhaust chamber where the arc is split with the help of arc splitters and ultimately arc is quenched.

I.6- Oil Circuit Breaker

Oil Circuit Breakers are generally of two types and they are

i) Bulk Oil type or the Dead tank type (OCB)

ii) Minimum Oil Circuit Breaker(MOCB)

I.6.1. Bulk Oil type or the Dead tank type (OCB)

The bulk oil circuit breakers are those which use large volumes of oil for two specific purposes. These oils need large tanks which solve the purpose of arc quenching chamber. The oil is used for

a) Providing insulation from the live current carrying contacts

b) Serving as a medium of arc quenching.

The tank, that houses the current carrying contacts, is at ground potential. When the moving contacts open to initiate the circuit breaking process, an arc is struck inside the oil medium. Due to oil heating, it vapourizes to produce hydrogen and other

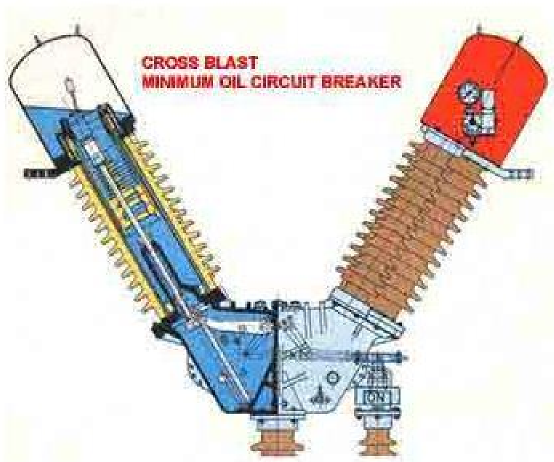
hydrocarbon gases. These gases generate high pressure in the vicinity of the arc and cool it. Subsequently, the arc can‟t sustain itself and gets quenched.

I.6.2. Minimum Oil Circuit Breaker (MOCB)

These types of circuit breakers utilize oil as the interrupting media. However, unlike bulk oil circuit breaker, a minimum oil circuit breaker places the interrupting unit in insulating chamber at live potential. The insulating oil is available only in interrupting chamber. The features of designing MOCB is to reduce requirement of oil, and hence these breaker are called minimum oil circuit breaker.

As the volume of the oil in bulk oil circuit breaker is huge, the chances of fire hazard in bulk oil system are more. For avoiding unwanted fire hazard in the system, one important development in the design of oil circuit breaker has been introduced where use of oil in the circuit breaker is much less than that of bulk oil circuit breaker. It has been decided that the oil in the circuit breaker should be used only as arc quenching medium, not as an insulating media. In this type of circuit breaker the arc interrupting device is enclosed in a tank of insulating material which as a whole is at live potential of system. This chamber is called arcing chamber or interrupting pot. The gas pressure developed in the arcing chamber depends upon the current to be interrupted. Higher the current to be interrupted causes larger the gas pressure developed inside the chamber, hence better the arc quenching. But this puts a limit on the design of the arc chamber for mechanical stresses. With use of better insulating materials for the arcing chambers such as glass fiber, reinforced synthetic resin etc, the minimum oil circuit breaker are able to meet easily the increased fault levels of the system.

Working principle or arc quenching in minimum oil circuit breaker



Working Principle of minimum oil circuit breaker is described below. In a minimum oil circuit breaker, the arc is drawn across the current carrying contacts is contained inside the arcing chamber. Hence the hydrogen bubble formed by the vaporized oil is trapped inside the chamber. As the contacts continue to move, after its certain travel an exit vent becomes available for exhausting the trapped hydrogen gas. There are two different types of arcing chambers, available in terms of venting. One is axial venting and other is radial venting. In axial venting, gases (mostly Hydrogen), produced due to vaporization of oil and decomposition of oil during arc, will sweep the arc in axial or longitudinal direction.

Let‟s have a look on working principle Minimum Oil Circuit Breaker with axial venting arc chamber. The moving contact has just been separated and arc is initiated in MOCB.

The ionized gas around the arc sweeps away through upper vent and cold oil enters into the arcing chamber through the lower vent in axial direction as soon as the moving contact tip crosses the lower vent opening and final arc quenching in minimum oil circuit breaker occurs.

The cold oil occupies the gap between fixed contact and moving contact and the minimum oil circuit breaker finally comes into open position.

Whereas in case of radial venting or cross blast, the gases sweeps the arc in radial or transverse direction.The axial venting generates high gas pressure and hence has high dielectric strength, so it is mainly used for interrupting low current at high voltage.

On the other hand radial venting produces relatively low gas pressure and hence low dielectric strength so it can be used for low voltage and high current interruption. Many times the combination of both is used in minimum oil circuit breaker so that the chamber is equally efficient to interrupt low current as well as high current. These types of circuit breaker are available up to 8000 MVA at 245 KV.

I.7- Vacuum Circuit Breaker or VCB

A vacuum circuit breaker is such kind of circuit breaker where the arc quenching takes place in vacuum. The technology is suitable for mainly medium voltage application. For higher voltage vacuum technology has been developed but not commercially viable. The operation of opening and closing of current carrying contacts and associated arc interruption take place in a vacuum chamber in the breaker which is called vacuum interrupter. The vacuum interrupter consists of a

steel arc chamber in the centre symmetrically arranged ceramic insulators. The vacuum pressure inside a vacuum interrupter is normally maintained at 10 – 6 bar.

The material used for current carrying contacts plays an important role in the performance of the Vacuum circuit breaker. Cu-Cr is the most ideal material to make VCB contacts. Vacuum interrupter technology was first introduced in the year of 1960. But still it is a developing technology. As time goes on, the size of the vacuum interrupter is being reduced from its early 1960‟s size due to different technical developments in this field of engineering. The contact geometry is also improving with time, from butt contact of early days it gradually changes to spiral shape, cup shape and axial magnetic field contact. The vacuum circuit breaker is today recognized as most reliable current interruption technology for medium voltage switchgear. It requires minimum maintenance compared to other circuit breaker technologies.

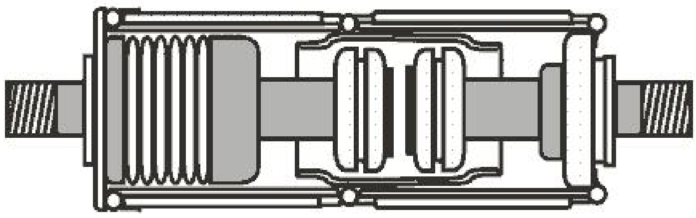
I.7.1. Advantages of vacuum circuit breaker or VCB

Service life of vacuum circuit breaker is much longer than other types of circuit breakers. There is no chance of fire hazard as oil circuit breaker. It is much environment friendly than SF6 Circuit breaker. Besides, the contraction of VCB is much user friendly. Replacement of vacuum interrupter (VI) is much convenient.

I.7.2 Operation of vacuum circuit breaker

The main aim of any circuit breaker is to quench arc during current zero crossing, by establishing high dielectric strength in between the contacts so that reestablishment of arc after current zero becomes impossible. The dielectric strength of vacuum is eight times greater than that of air and four times greater than that of SF6 gas. This high dielectric strength makes it possible to quench a vacuum arc within very small contact gap. For short contact gap, low contact mass and no compression of medium the drive energy required in vacuum circuit breaker is minimum. When two face to face contact areas are just being separated to each other,

they are not done so instantly. Instead, as the contact area on the contact face is being reduced and ultimately comes to a point and then they are finally de-touched. This happens in a fraction of micro second. At this instant of de-touching of contacts in a vacuum, the current through the contacts concentrated on that last contact point on the contact surface and makes a hot spot there. As the medium is vacuum, the metal on the contact surface gets easily vaporized due to that hot spot and create a conducting media for arc path. Therefore, the material constituting the arc is very small and thus a feeble arc is established even with high current interruption. The arc will be initiated and continues until the onset of next current zero. Th figure below shows the cross section assembly of a VCB.



Cross section of Vacuum Interrupter

At current zero this vacuum arc is extinguished and the conducting metal vapor is re-condensed on the contact surface. At this point, the contacts are already separated hence there is no question of re-vaporization of contact surface, for next cycle of current. That means, the arc cannot be reestablished again. In this way vacuum circuit breaker prevents the reestablishment of arc by producing high dielectric strength in the contact gap after current zero.

There are two types of arc shapes. For interrupting current up to 10 kA, the arc remains diffused and the form of vapor discharge and cover the entire contact surface. Above 10 kA the diffused arc is constricted considerably by its own magnetic field and the contracts. The phenomenon gives rise to over heating of contacts at its center. In order to prevent this, the design of the contacts should be such that the arc does not remain stationary but keeps travelling by its own magnetic field. Specially

designed contact shape of vacuum circuit breaker makes the constricted stationary arc travel along the surface of the contacts, thereby causing minimum and uniform contact erosion.

I.8- SF6 Circuit Breaker

A circuit breaker in which the current carrying contacts operate in sulphur hexafluoride or SF6 gas is known as an SF6 circuit breaker. SF6 has excellent insulating property and it has a high electro-negativity. Therefore, it has high affinity of absorbing free electrons. Whenever a free electron collides with the SF6 gas molecule, it is absorbed by that gas molecule and forms a negative ion with the following processes.

$$SF_6 + e = SF_6^-$$
$$SF_6 + e = SF_5^- + F$$

These negative ions are much heavier than a free electron and therefore the over all mobility of the negatively charged particle in the medium is considerably reduced compared to other gases. As the mobility of charged particle is reduced, therefore the severity of arcing shall also be affected and reduced.

Hence, for heavier and less mobile charged particles in SF6 gas, it acquires very high dielectric strength. Not only the gas has a good dielectric strength but also it has the unique property of fast recombination after the process of arcing is completed. The gas also has a very good heat transfer property. Due to its low gaseous viscosity (because of less molecular mobility) SF6 gas can efficiently transfer heat by convection. So due to its high dielectric strength and high cooling effect SF6 gas is approximately 100 times more effective arc quenching medium compared to air. Due to these unique properties of this gas, SF6 circuit breaker is used in complete range of medium voltage and high voltage electrical power system. These circuit breakers are available for the voltage ranges from 33KV to 800KV and even more.

I.8.1 Disadvantages of SF6 CB

The SF6 gas is identified as a greenhouse gas, safety regulation are being introduced in many countries in order to prevent its release into atmosphere.

Puffer type design of SF6 CB needs a high mechanical energy which is almost five times greater than that of oil circuit breaker.

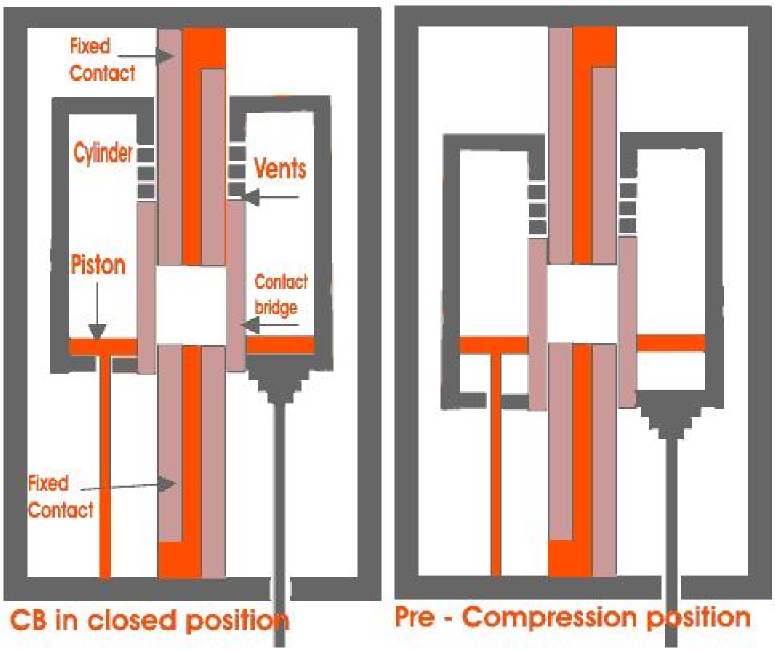
I.8.2 Types of sf6 circuit breaker

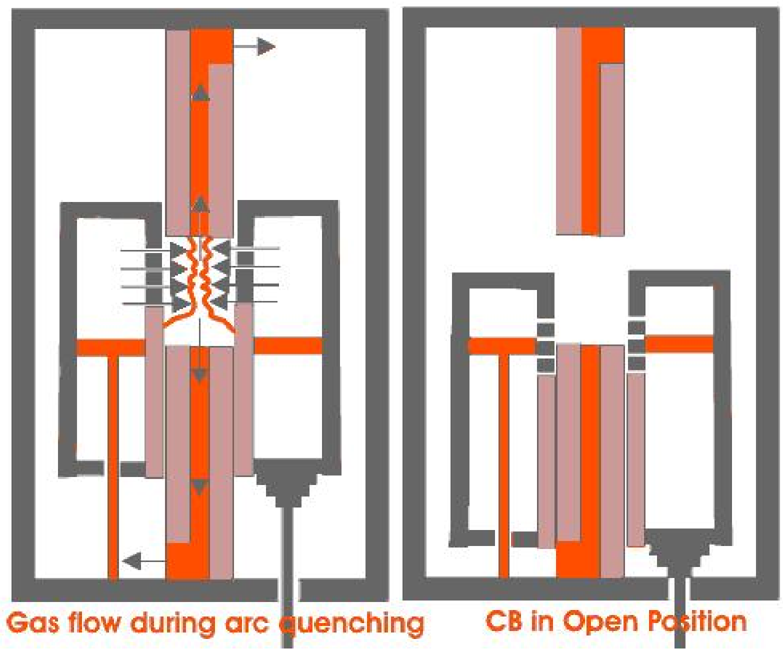
There are mainly three types of SF6 CB depending upon the voltage level of application-

1. Single interrupter SF6 CB applied for up to 245 KV(220 KV) system.
2. Two interrupter SF6 CB applied for up to 420 KV(400 KV) system.
3. Four interrupter SF6 CB applied for up to 800 KV(715 KV) system.

I.8.3 Working of SF6 circuit breaker

The working of SF6 CB of first generation was quite simple it is some extent similar to air blast circuit breaker. Here SF6 gas was compressed and stored in a high pressure reservoir. During operation of SF6 circuit breaker this highly compressed gas is released through the arc in breaker and collected to relatively low pressure reservoir and then it pumped back to the high pressure reservoir for re utilize.





The working of SF6 circuit breaker is little bit different in modern time. Innovation ofPuffer type design makes operation of SF6 CB much easier. In Puffer type design, the arc energy is utilized to develop pressure in the arcing chamber for arc quenching.

Here the breaker is filled with SF6 gas at rated pressure. There are two fixed contact fitted with a specific contact gap. A sliding cylinder bridges these to fixed contacts. The cylinder can axially slide upward and downward along the contacts. There is one stationary piston inside the cylinder which is fixed with other stationary parts of the SF6 circuit breaker, in such a way that it cannot change its position during the movement of the cylinder. As the piston is fixed and cylinder is movable or sliding, the internal volume of the cylinder changes when the cylinder slides.

- During opening of the breaker the cylinder moves downwards against position of the fixed piston hence the volume inside the cylinder is reduced which produces compressed SF6 gas inside the cylinder. The cylinder has numbers of side vents which were blocked by upper fixed contact body during closed position. As the cylinder move further downwards, these vent openings cross the upper fixed contact, and become unblocked and then compressed SF6 gas inside the cylinder will come out through this vents in high speed towards the arc and passes through the axial hole of the both fixed contacts. The arc is quenched during this flow of SF6 gas.

- During closing of the circuit breaker, the sliding cylinder moves upwards and as the position of piston remains at fixed height, the volume of the cylinder increases which introduces low pressure inside the cylinder compared to the surrounding. Due to this pressure difference SF6 gas from surrounding will try to enter in the cylinder. The higher pressure gas will come through the axial hole of both fixed contact and enters into cylinder via vent and during this flow; the gas will quench the arc.

I.9- DC Circuit Breaker

It is well known that DC has no natural current zero. Therefore, the current either needs to reduced, by lengthening of the arc or cooling or by forced reduction of the current to zero. For lower voltage cases, a simple resistance and inductive coil connected across a switch forces the current to reduce to zero. Such a scheme is particularly being successful when the current magnitude is small. For higher voltage and current cases, a method that combines forced current reduction and grid control mechanism is applied.

Forced reduction of current zero: In this method an oscillatory LC network is utilized to let an oscillatory current flow in opposite direction to that of the direct current (DC). The moment the oscillatory current magnitude exceeds the DC value, the breaker current falls to zero temporarily. This helps in quenching the arc. The peak oscillatory current of the LC circuit should be more than the DC value through the breaker. The scheme operation can be understood from the figure given below. A normally open (NO) and a Normally Closed (NC) auxiliary breakers are utilized to discharge and charge the capacitor of the LC unit. The capacitor first is charged to line voltage through the L and R through the NC breaker. At the desired instant of main C.B opening, the capacitor discharges through the L when, the NO breaker becomes closed and NC becoming open.

In this scheme, the value of C is so chosen that, the rise time constant of the line voltage is smaller than the charging time constant of C, which ensures that the voltage across the C is maintained for longer time. Similarly the value of L is so chosen that, the rise time constant of the line current should be more than the changing time constant of the oscillatory current, which ensures that the oscillatory current reaches the load current quickly.

Method of Grid Control: All transient faults which die out immediately, can be controlled by method of grid control. In this method the faults can be switched out

gradually in an artificial manner by forcing the whole system voltage to reduce to zero temporarily, with the help of converter grid control. Fast acting isolating switches are then used to isolate the faults. With this method also the short circuit current magnitude can be reduced considerably to levels much below the full, load levels so that severity of the fault can be reduced. This partial current reduction method is sufficient in the case of unsustained faults.

I.9.1- Miniature circuit breaker or MCB

Nowadays we use more commonly miniature circuit breaker or MCB in low voltage electrical network instead of fuse. The MCB has some advantages compared to the fuse.

1. It automatically switches off the electrical circuit during abnormal condition of the network means in over load condition as well as faulty condition. The fuse does not sense but miniature circuit breaker does it in more reliable way. MCB is much more sensitive to over current than fuse.
2. Another advantage is, as the switch operating knob comes at its off position during tripping, the faulty zone of the electrical circuit can easily be identified. But in case of fuse, fuse wire should be checked by opening fuse grip or cutout from fuse base, for confirming the blow of fuse wire.
3. Quick restoration of supply cannot be possible in case of fuse as because fuses have to be rewired or replaced for restoring the supply. But in the case of MCB, quick restoration is possible by just switching on operation.
4. Handling MCB is more electrically safe than fuse.

Because of many advantages of MCB over fuse units, in modern low voltage electrical network, miniature circuit breaker is mostly used instead of backdated fuse unit.

Only one disadvantage of MCB over fuse is that this system is more costlier than fuse unit system.

Working principle MCB

There are two arrangement of operation of miniature circuit breaker. One due to thermal effect of over current and other due to electromagnetic effect of over current. The thermal operation of miniature circuit breaker is achieved with a bimetallic strip whenever continuous over current flows through MCB, the bimetallic strip is heated and deflects by bending. This deflection of bimetallic strip releases mechanical latch. As this mechanical latch is attached with operating mechanism, it causes to open the miniature circuit breaker contacts. But during short circuit condition, sudden rising of current, causes electromechanical displacement of plunger associated with tripping coil or solenoid of MCB. The plunger strikes the trip lever causing immediate release of latch mechanism consequently open the circuit breaker contacts. This was a simple explanation of miniature circuit breaker working principle.